Transparent light emitting devices based on WS_2 monolayers in a scalable vertical architecture

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Abstract

Transition metal dichalcogenides (TMDCs) have emerged as highly promising semiconducting materials for ultrathin optoelectronic devices. Over the past years, upscaling techniques like metalorganic chemical vapor deposition (MOCVD) paved a way towards industrially relevant device architectures. As a consequence, macroscopic light emitting devices based on monolayer TMDCs became feasible [1], even on flexible substrates [2]. In this contribution we make use of the high transparency of TMDCs: We use silver nanowire networks as transparent electrodes to achieve fully transparent LEDs with monolayer WS_2 as the active material.

The LEDs were fabricated on ITO-coated glass with an organic polymer as the hole supporting layer. After transfer of a WS_2 monolayer as the active layer, ZnO quantum dots were spin-coated on top as an electron supporting layer. Finally, silver nanowires in ethanol with average diameters and lengths of 49 nm and 88 µm, respectively, were spin coated onto the LEDs. They provide electrodes with a sheet resistance below 10 Ω/□ and a transmittance of nearly 80 %. The LEDs show the characteristic red luminescence of WS_2 monolayers from areas of several mm^2 with a turn-on voltage of 2.5 V. The complete device exhibits an average transmittance of about 60 % in the visible spectral region.

In a second step, the spin-coated ZnO nanoparticles were replaced by a continuous 40 nm thick ZnO layer. Here, we employed atmospheric pressure spatial atomic layer deposition (AP-SALD) as a precise tool for scalable deposition of oxides with defined thickness. This design resulted in a further improvement of luminance and external quantum efficiency by a factor of 5. Our results broaden the range of possible future optoelectronic devices based on 2D materials.

References

[1] D. Andrzejewski, H. Myja, M. Heuken, A. Grundmann, H. Kalisch, A. Vescan, T. Kümmell, G. Bacher, ACS Photonics 6, 1832 (2019)
[2] D. Andrzejewski, R. Oliver, Y. Beckmann, A. Grundmann, M. Heuken, H. Kalisch, A. Vescan, T. Kümmell, G. Bacher, Adv. Optical Mater. 8, 2000694 (2020)